Sustaining Site Productivity on Forestlands

A User's Guide to Good Soil Management

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to Good Soil Management

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Foreword

Acknowledgments

In 1983, forest soil experts from the USDA Forest Service, California Department of Forestry (CDF), Soil Conservation Service, University of California, and the forestry industry agreed on the need for a guide to better soil management on nonindustrial, private forestlands in California. The CDF chartered the Forest Soils Productivity Advisory Committee to facilitate preparation of this guide. Committee members, together with other experienced managers of forest soils, contributed papers that were compiled, reviewed, and edited. Photographs and illustrations were provided by the authors and by Aaron Gelobter, USDA Forest Service, Pacific Southwest Region.

This publication represents our current understanding of how to maintain California's forest productivity by protecting its soil. Conceived, written, and edited independent of any of our agencies or organizations, the ideas and opinions expressed here do not necessarily support existing policies or practices of those organizations. We do, however, acknowledge their implicit support and, in particular, CDF's financial and staff support. The Committee and the authors accept responsibility for any errors or omissions.

Is this volume really needed? After all, isn't it obvious to any resident of this agricultural state that productive soils are a key to prosperity? Perhaps it is obvious. Perhaps people are aware that California's agricultural productivity—and the wealth of our state—depend largely on sound soil management. However, there may be important distinctions in our perception of agricultural and forest soils. Agricultural soils have a long history of capital investment. They did not come "ready made" with a crop. Rather, they had to be cultivated, sowed, irrigated, and fertilized to produce products of broad commercial value. In a sense, we had to create a resource. Today, we recognize the importance of agricultural soil productivity and the need we have to sustain it.

In contrast, forest soils are taken almost for granted. Combined with a favorable climate and the passage of time, they have produced forest crops that were waiting for us on our arrival—and still are. We had little to do with producing the natural forest. Management investments have been low and have been keyed mainly to taxes, protection, extraction, and regeneration. Soil productivity is something we inherited. And because we had no hand in developing soil productivity, we sometimes assume that it is perpetual. Few of us have the training to see that the productivity we inherited took centuries to build. Through careless acts or ignorance, this productive legacy can be lost or severely degraded. To combat a possible myopic vision of forest soils, we believe this volume is needed.

Site productivity and soil are key words in the title and text of this cooperative effort, but there is more to it than that. The underlying subject is dollars. Yes dollars!

Perhaps yours, or those of a client or government agency, or of a future owner of the forestland you now manage. Surely, we can rally around concepts related to dollars.

In New Zealand, removing only 1 inch of topsoil by tractor was discovered to cause a 20 percent drop in site productivity. Think about that in terms of dollars and cents, if that were your land! Given enough time, a forest can rebuild its soil through rainfall, litterfall, and rock weathering, but the growth opportunities lost through poor but preventable forest practices are lost forever. Using the New Zealand example, lost soil productivity means that periods between harvests (rotations) will be longer and wood production rates will be less.

In California, forestry is changing. So are the demands that are placed on its soils. Increased mechanization, reduced rotation lengths, whole-tree harvesting, cull log "YUMing," and slash removal for fuel reduction are emerging forest practices that potentially can seriously damage soil productivity. At the same time, research on soil characteristics and forest processes is yielding reams of written findings. Applying research to forest management conditions is not easy, however. Most soil information resides in highly technical reports that have not been condensed to a form easily usable to forester or landowner.

This publication forges a link between soil research knowledge and the practice of sound forestry. Directed to foresters and landowners, the chapters describe how soil productivity is affected by soil properties and silvicultural practices. Alternatives and mitigation measures are suggested for practices that threaten productivity, and sources of additional assistance are given. Technical terms with particular significance to forest productivity appear either as **bold-face** headings, or are *italicized* and defined where appropriate. Specific references also are cited throughout the text by their authors and by the year of publication. These citations are listed in the ***References*** section at the end of this volume.

This publication also is directed to the growing numbers of landowners whose main ownership interest centers on recreation, wildlife values, aesthetics, solitude—or simply the desire to improve forestland for the benefit of the next generation. In California, one fifth of the commercial forest area is owned by private, nonindustrial landowners. Among them, only one in five list wood production as their principal reason for ownership. But, regardless of the landowners' main management interests, road building, vegetation manipulation, and some harvesting or other timber stand improvement may be needed to achieve a desired goal. Thus, soil productivity and good land stewardship are pertinent to all of us, regardless of our objectives.

The National Wildlife Federation and the Soil Conservation Service, through the news media, are transmitting to millions of citizens this simple message: "Soil—we can't grow without it." As a forester, I know we need more than just soil. We need *productive soil* to sustain or optimize forest growth over time, maintain management flexibility, and minimize costs. Our message to you is this: "Soil productivity—we can't grow and prosper without it."

—John L. Ronald

I.

The Soil as a Fundamental Resource

ROBERT F. POWERS

Soil is more than farmer's dirt, or a pile of good topsoil, or engineering material; it is a body of nature that has its own internal organization and history of genesis.

—Hans Jenny
Professor Emeritus, Department of Soil Science
University of California, Berkeley

Soil, the earth's unconsolidated mineral and biological skin, has immense value. Formed from the interactions of climate, organisms, landscape relief, parent material, and time, it is a primary natural resource from which many other resources and our most valued commodities flow.

One such resource is the forest.

The better the soil, the more productive and healthy is the forest that rises from it. Soils and forests have developed together, each nurturing changes in the other. But while forests mature in a few decades, their soils often need millenia to reach peak productivity. Thus, only after many generations of forests pass does a forest soil mature.

Forests are more than a gathering of trees. With their soils they form ecosystems with many emerging properties. Often, these properties can be harnessed to yield products useful to society. Wood fiber, sustained water quality and flow, wildlife habitat, and recreational values all are useful products emerging from productive forest ecosystems. A less obvious product is the air we breathe, and even this comes in large measure from young, vigorous forests. Although covering only 10 percent of the earth's surface, forests provide nearly half of our oxygen. They also sequester about ten times more carbon than is contained in the atmosphere, thereby serving as a buffer against a buildup of atmospheric carbon dioxide—a greenhouse gas. There is no doubt that in both the short and long run, our well-being is keyed to productive forest soils. Yet, forestland is shrinking in the United States and abroad through land conversion, forest exploitation, and soil degradation.

For our own interests, and those of generations to follow, we must be good stewards of our forestlands. Good stewardship means taking the time to understand key principles of forest soil science that affect site quality—the capacity of the land for sustaining wood growth, and to recognize and avoid forest management practices that may degrade one of our most fundamental resources. The first step is to see the soil as more than merely a collection of weathered minerals. In fact, it is a body of many parts in continual change. The soil contains horizontal layers called *horizons*, which vary in thickness and in chemical, physical, and biological properties—and all interact to affect forest vigor and growth.

The layer of fresh or decaying organic litter found at the surface, just above the first layer that clearly is mineral, is called the *"O" horizon* or *forest floor*. This layer is a vital source of carbon that provides the energy needed by many soil microorganisms that improve soil structure and fertility. It also provides nitrogen—a nutrient needed in sizable amounts by all living things. Further, the O horizon protects the mineral layers below against erosion by wind and water, and against compaction by heavy loads. The O horizon also houses fungi and small animals important in transforming organic matter into simpler products that move into the soil. Some of these form "glues" to help bind mineral particles together. Others release nutrients that nourish forest plants.

Just below the organic layer is the *"A" horizon.* Although mainly mineral, this layer also contains partially decomposed organic matter from the O horizon above it, and its color is darker than the mineral horizons below. The A horizon is especially rich in nutrients—much richer than lower horizons—and is populated with small soil organisms whose activity is vital in improving soil structure (which allows the free passage of water and air) and in transporting organic materials from above. The abundance of fine, feeder roots in the A horizon reflects its significance as a zone of high fertility.

As soils age, a *"B" horizon* forms in the subsoil beneath the A horizon. This finer-textured layer marks an accumulation zone for colloid-sized particles transported downward from the A horizon. The B horizon is particularly important in storing water for use by vegetation, is a secondary source of nutrients, and provides extra depth for anchoring tree roots. However, the low organic matter content of the B horizon makes it particularly prone to compaction if the overlying O and A horizons are reduced or removed. And with extreme soil development, the clay content may become great enough to produce a "pan" that is a barrier to root, air, and water penetration.

Beneath the B horizon (or the A horizon in less-developed soils) is the *"C" horizon*—a layer of weathered, relatively infertile, and often coarse-textured mineral matter. The C horizon extends to bedrock or to other unweathered material, and is important in the deep anchoring of tree roots.

Clearly, the fertility and resiliency of a forest soil depend on the properties of its surface horizons, and these layers are linked fundamentally to the long-term productivity of the forest. Accordingly, the following chapters are aimed at providing a basic knowledge of soil properties and how they relate to forest productivity and forest management practices. We hope that better understanding will make better land stewards of us all.

II.

Forest Productivity Factors

Charles B. Goudey

In a timber management sense, *forest site productivity* is the capacity of land to grow trees. Usually this capacity is expressed as a *site index* (the height trees attain at a standard reference age) or in potential volume growth of trees. Productive capacity depends on inherent site properties—location, soil, and the tree species that grow on the land. How much of this capacity is realized by society and how much of it is altered depends on management practices.

Factors Affecting Productivity

Site factors

Site location reflects interrelated environmental factors that affect productive capacity—the varying amounts of light, heat, and moisture that are deposited—as well as topographic position, aspect, and climate. Soil influences forest productivity through its capacity to supply tree roots with the water, nutrients, and air needed for growth. This capacity varies among soils and can change dramatically over short distances.

Tree species reflects a tree's inherent ability to grow at a particular location. For example, some species are adapted to cold sites or to shorter day lengths. Others are adapted to warmer temperatures or to soils with limited capacities to supply nutrients and water. Natural mortality concerns production losses due to fire, insects, and diseases.

Management factors

Management determines how much of a site's inherent productive capacity is realized to produce usable wood. The amount of site potential captured depends on the choice of tree species, stocking, natural mortality, and the intensity of forest management. Low-intensity management captures less of a site's potential for growing wood because a large share of the environmental and soil resources will be diverted away from crop trees. High-intensity management captures a greater share of (and may even improve on) a site's potential, but carries with it a risk of degrading soil properties important to the future capacity of the land for growing trees.

Soil Properties Affecting Forest Productivity

The soil is fundamentally important for timber production. One-fourth or more of a tree's mass is located in the soil, which provides both the water and mineral nutrients needed for survival and growth. Soil properties affecting the supply of air, nutrients, and water to plant roots include structure, texture, stone content, strength, density, porosity, organic matter content, mineralogy, reaction (pH), microorganisms, and temperature. The influence and interactions of some of these properties on tree growth are described in the following sections.

Soil's physical properties

Soil's most important physical functions are:

(1) water storage

(2) air and water circulation

(3) root support

In California, *available moisture* usually is a major factor limiting tree growth. Because California summers are dry, survival and growth of forest trees depends on water stored in the soil from winter snow or rain. Exceptions are trees receiving summer moisture from a water table or from fog drip along the coast.

Soil air is the primary source of oxygen for plant roots and soil microorganisms. As air and water circulate in the soil, not only are oxygen and water carried to roots, but gases given off by roots and decaying organic matter are carried away. Soils with poor aeration are associated with poor tree growth (Pritchett 1979). The main soil properties influencing air and water movement and water storage are porosity, texture, structure, depth, and spatial variation.

Soil porosity is that portion of the soil not occupied by solid particles. Between 50 and 70 percent of the volume in surface layers of California forest soils is pore space. These pores contain air and moisture in constantly changing proportions. In a dry soil, pore spaces are occupied largely by air. In a waterlogged soil, they are filled with water. Pore size is important, too. Large ("macro") pores allow rapid intake and draining of water and circulation of air. Small ("micro") pores provide water storage.

Soil texture refers to the relative proportion of different sizes of solid soil particles. Such textural terms as sandy loam, loam, and clay loam reflect the proportions of sand, silt, and clay. The amount of water and nutrients a soil can store and supply to plants varies by texture. For example, a clay loam can store more water for plant growth than a sandy loam.

Many California forest soils contain rock fragments, which proportionally reduce the volume of soil available for water and nutrient storage. *Soil structure* is the arrangement of soil particles into natural aggregates (Fig. 1). Platy, blocky, and granular are some of the structure forms. The type of structure indicates the relative abundance of pores and ease of root penetration. For example, soils with granular structure allow easy root penetration and have a large pore space for water transport and storage. Some soils, such as those with very high sand content, do not form structure. These soils also have varying amounts of pore space and ease of root penetration.

The ease by which roots move in the soil to find water and nutrients greatly influences forest productivity. *Soil depth* is an index of soil volume. The deeper the soil, the greater its capacity to store water and nutrients and to anchor tree roots. Shallow soils, or those with high water tables, produce trees with shallow root systems. Such trees are particularly prone to water stress during unusually dry years, when the soil is depleted of stored water or the water table drops. Shallow-rooted trees also are windthrown readily during high winds in winter when the soil may be saturated. Deep, well-drained soils produce trees with well-anchored root systems.

Variations in soil properties occur laterally and vertically. Sometimes these changes are subtle; sometimes they are striking. Soils commonly contain horizons with contrasting texture, structure, and other properties. Sometimes, pore characteristics and ease of root penetration change abruptly at soil horizon boundaries. Structure, texture, soil depth, and other properties also vary horizontally, and can differ greatly within short distances. Examples of vertical and horizontal variation are shown in Figure 1. Information about soil texture, structure, depth, variability, and many other properties often can be found in soil survey reports (see chapter IV).

Management activities—skidding logs on the ground or preparing a site for regeneration—can modify soil structure, porosity, and depth. Any activity that exerts compactive forces on the soil can alter structure, increase density, decrease porosity, and thereby retard aeration and root elongation (Alexander and Poff 1985). The adverse effects of *soil compaction* on timber stand growth (Fig. 2) have been documented by studies in California and elsewhere (Alexander and Poff 1985, Helms, Hipkin, and Alexander 1986). Soil depth can be decreased by mechanical means (Fig. 3), as in machine piling, or by erosion. This can reduce soil water and nutrient supply and expose subsoils that are less favorable for plant growth. For example, removing porous surface soil means that feeder roots must contend with a less porous subsoil. Other effects of soil loss on productivity are described below.

Soil fertility

A soil's ability to provide air, water, and nutrients in adequate amounts and balance for plant growth is referred to as its *fertility*. This involves many chemical and biological processes. The natural fertility of California forest soils varies by parent rock, reaction (pH), temperature, and other factors. For example, soils formed from volcanic rocks are relatively high in fertility, whereas soils formed from serpentine—a green-colored rock low in calcium—are relatively infertile.

Most plant nutrients in the soil originate from rock weathering. The notable exceptions are nitrogen and sulfur, which are incorporated into the soil from the atmosphere by precipitation and "fixed" by bacteria, algae, and a symbiosis of microorganisms with some plants. Nitrogen is needed for tree growth in greater amounts by weight than any other soil-supplied nutrient, except water. Most nitrogen potentially available for tree growth is associated with organic matter and clay minerals in the topsoil (Powers 1989; Atzet et al. 1989) (Fig. 4). Zinke (1960) found that higher site indices coincided with larger total amounts of soil nitrogen.

Most nutrients, including nitrogen, are concentrated in the forest floor and topsoil and decrease with depth. The soil is a large storehouse of nutrients, but its supply is limited. Nutrients taken up by trees from the soil and forest floor accumulate in the leaves, limbs, trunk, and roots of the tree. Amounts stored in these parts vary with age. Eventually, plant parts die and nutrients are returned as organic litter to the soil where, through decomposition and mineralization, they become available again to plants.

Replenishing soil nutrients through this cycling process is necessary for plant growth to continue at an adequate pace. In general, the concentration of nutrients in plant materials decreases with increasing diameter—the thicker the material, the lower the concentration. For example, tree trunks usually contain lower concentrations of nutrients than do other parts of the tree and the forest floor. Consequently, removing the trunk has the least effect on soil fertility, whereas removing all or nearly all standing vegetation and litter may lead to nutrient deficiencies.

There is a difference, of course, between "concentration" and "content." Although nutrient concentrations are low in tree trunks, the sheer size of large trees means that their massive trunks may contain large absolute amounts of such nutrients as calcium. Most nutrients are associated with the organic matter and clay minerals in the topsoil. Organic matter is composed of plant and animal residues that accumulate in the upper part of forest soils and decrease with depth. The decompositiion of soil organic matter by fungi and bacteria is the key to converting nutrients into forms usable by plants. The kinds and amount of clay minerals also influence nutrient availabiity and storage. Both short- and long-term soil fertility is controlled by the nutrients held by organic matter and clay minerals in the topsoil. The thickness of the topsoil—and thereby, the amount of organic material on or in the soil—can be modified with management.

The greatest potentially adverse long-term effect on forest productivity comes from removing the litter layer and part or all of the topsoil. A California study showed that pine plantations with major topsoil piling had lost so much productive capacity that fertilization increased growth by over 40 percent. By contrast, in plantations with minor topsoil piling, growth increased only 15 percent following fertilization (Powers, Webster, and Cochran 1988). This does not mean that "scalping" soil and fertilizing is a way to increase yields. Rather, it demonstrates how much of soil's productive capacity is contained in the upper part of the topsoil and how much it affects growth. The litter layer and soil organic matter also can be lost by burning. The amount of loss is proportional to the intensity of the burn, and can be minimized by consuming less material and burning at lower temperatures (McColl and Powers 1983).

Soil condition

Productivity is usually greatest when the soil is at its best physically, chemically, and biologically. This does not mean that a deep, friable, clay loam high in organic matter will be found on every site. Productivity simply refers to the capacity of a soil for growing trees, given the site's parent material, topography, climate, vegetation, and management history. Maintaining or improving the productive capacity of soil requires a knowledge of soil condition. This knowledge will help in recognizing a soil's capabilities and limitations, and in finding ways to minimize management practices that adversely affect or permanently modify soil properties.

Soil loss, soil compaction, and **organic material loss** are categories of soil conditions used here to simplify discussion of management effects on soil properties and forest productivity. These categories, whether viewed individually or in combination, have the greatest potential for reducing forest productivity. They are described below, and are used in chapter III to display the potential long-term effects of management practices on site productivity.

Soil loss is the removal of surface soil through mechanical means (piling, raking) or erosion. The effects of soil loss on productivity are due primarily to reductions in the supply of nutrients and water. Aeration also can be reduced when porous topsoil is lost and less porous subsoil is exposed. Different soils have different sensitivities to soil loss due to variation in topsoil thickness. Removing soil from a site can impair forest productivity permanently, because soil is a nonrenewable resource (hundreds to thousands of years may be needed to rebuild sizable losses).

Soil compaction (Fig. 5) causes a reduction in soil porosity and an increase in soil density. This affects productivity by retarding root growth and the circulation of air and water.

Organic material loss from the forest floor and soil directly affects short- and long-term plant nutrient supply. Organic material on the soil surface can provide erosion protection and lessen the effects of mechanical equipment. Soil organic matter also enhances some physical soil properties, including water retention, structure, porosity, and resistance to compaction.

Potential impacts of management practices on forest productivity are discussed in the chapters that follow, and are summarized by Powers (1989).

III.

Silvicultural Practices Impacting Productivity

Gary M. Nakamura

Silviculture, "the science and art of growing forest tree crops," is the heart of this chapter. Common silvicultural practices under the broad headings of ***Site Preparation***, ***Residue Management***, and ***Harvesting Methods*** are described and rated as to their maximum potential effect on soil productivity. Our ratings are based on "maximum," rather than "average," potential effects to show that certain practices carry a much greater risk to site productivity than do others if they are applied carelessly. Using our ratings requires a common understanding of what we mean by silvicultural systems and specific silvicultural practices, and how the choice of one practice may affect the choice of another—and in a sense, compounding our potential impact—through the next stage of management.

Definitions

Silvicultural systems

A silvicultural system is not merely a way of cutting trees. It consists of a complete, interrelated set of field operations to establish, tend, and replace forests according to established scientific principles. Five major silvicultural systems are recognized, and a sixth "modified" system is becoming popular. These are listed here in ascending order of soil disturbance and biomass removal.

1. Single tree selection. Individual trees are periodically harvested with the objective of maintaining a nearly complete forest cover. Logging residues are light and localized. Regeneration is continuous and usually occurs by natural seedfall. The result: a stand comprised of shade-tolerant trees varying in size and age.

2. Group selection. Small groups (not individuals) of similarly-sized trees are removed at intervals. Logging residues may be high in the small openings, but are low overall because the openings are dispersed throughout the stand. Openings are restocked naturally, or sometimes by planting. The result: a stand that appears to have an uneven-age structure (trees of differing ages and sizes). In fact, the stand is comprised of a mosaic of small, even-aged groups (trees of similar ages and sizes) that may be weeded or thinned until trees reach maturity.

3. Shelterwood. An entire stand is removed gradually through a sequence of cuttings extending over a fraction of the rotation. Logging residues can be sizable and continuous. The objective: to establish an even-aged stand (naturally or by planting) before completing the preceding rotation, and to maintain an overstory canopy to provide the young trees with some temperature protection. Once regeneration is established, the overstory or "shelterwood" may be removed. The new stand may be weeded, thinned, or fertilized before final harvest.

4. Seed trees. Nearly all the trees in a stand are harvested in a single cut. A few well-spaced "seed trees" showing superior form and cone production are left to provide seed for natural regeneration. Whenever feasible, seed trees are harvested after regeneration is secured. Typically, logging slash is heavy and continuous. The resulting even-aged stand may be weeded, thinned, or fertilized before final harvest.

5. Clearcutting. All trees in an area are harvested so that a new, even-aged stand can be produced. Usually, this yields a great amount of logging slash. Regeneration is secured either by planting or seeding. Weeding, thinning, or fertilization treatments may be applied before harvesting.

6. Biomass harvesting. Trunks, branches, and leaves—of some or all of the trees in a stand—are removed completely. In some cases, even root systems are taken. Although not a genuine silvicultural system, it differs enough from the five established systems in terms of its potential impact that it merits separate mention. Other systems aim merely to remove commercially valuable logs. Usually, foliage, twigs, and branches remain as residues. In contrast, the aim of biomass harvesting is to remove as much of the entire tree as possible so as to convert all of the material into a commercially useful product, such as fuel to produce energy. Biomass harvesting is an even-age management practice that usually is confined to clearcutting or heavy thinning operations.

Harvesting methods

The means by which trees are yarded from the woods in a logging operation is called harvesting. Choosing the most appropriate method depends on the size of the trees to be harvested, ruggedness of terrain, and the cost and availability of equipment. For example, horses can be used to yard small logs or trees on gentle, uniform slopes, while tractors generally are used for larger logs on flat to moderate slopes. For steep slopes and large materials, cable yarding is common. Feller-bunchers (Fig. 6) bring speed and maneuverability to operations previously dominated by crawler tractors, and are particularly useful in biomass harvesting. Helicopters are used to "fly" logs out of steep, rugged terrain or from particularly sensitive areas such as stream zones.

Each type of equipment, by virtue of its weight and pattern of operation, has impact on the soil. The density of roads and landings is an obvious by-product of the harvesting method. Helicopter operations have little impact; tractor operations have many impacts. Forestland devoted to roads and landings essentially is removed from the productive land base and is not discussed in detail here.

Silvicultural practices

Harvesting, type conversion, and normal stand growth invariably produce residues that can physically and biologically bar regeneration and may pose a fire or insect risk to the developing stand. Generally, these residues must be cleared or modified. In site preparation, a regeneration site is cleared of residues and competing vegetation. In residue management, the residues left following harvest are reduced or removed. Thinning, weeding, and fertilization treatments practiced at intermediate stages of stand development are thought to have little, if any, detrimental effects on soil properties at any single entry.

Silvicultural impacts

Table 1 presents the maximum potential effect of a broad array of silvicultural practices on:

Soil loss—removal of soil and the water and nutrients it stores.

Soil compaction—reduction in soil porosity and increase in density.

Organic material loss—removal of nutrients and alteration of soil physical conditions.

These practices will be described in more detail in the two sections that follow. More detailed information can be found in the ***References*** section at the end of this volume.

Productivity loss—an overall productivity loss rating summarizing the collective potential impact of the three individual soil ratings.

Each practice is rated according to its *maximum potential effect* on site productivity. Maximum potential effect means the most severe impact possible when that practice is used under the *worst possible conditions*..

Table 1. Maximum potential effects of silvicultural practices on site productivity[1]

Silvicultural practice	Soil loss	Soil compaction	Organic loss	Productivity loss
Site Preparation				
Machine piling	VH[2]	VH	VH	VH
Terracing	VH	VH	VH	VH
Ripping or disking	M	L	L	M
Herbicide	L	L	L	L
Broadcast burning	H	M	H	H
Residue management				
Underburning	M	L	M	M
Lop and scatter	L	L	L	L
Chipping	L	L	L	L
Whole-tree harvesting	H	H	H	H
Yarding large residues	M	M	M	M
Single tree selection				
Feller-buncher yarding	M	M	L	M
Tractor yarding[3]	L	M	L	L
Cable yarding	L	L	L	L
Horse yarding	L	L	L	L
Helicopter or balloon yarding	L	L	L	L
Group selection				
Feller-buncher yarding	M	H	M	M
Tractor yarding	M	H	M	M
Cable yarding	L	L	M	L
Horse yarding	L	L	M	L
Helicopter or balloon yarding	L	L	M	L
Shelterwood harvest				
Feller-buncher yarding	M	H	M	M
Tractor yarding	M	M	M	M
Cable yarding	L	L	M	L
Horse yarding	L	L	M	L
Helicopter or balloon yarding	L	L	M	L
Seed tree harvest				
Feller-buncher yarding	H	H	M	H
Tractor yarding	H	H	M	H
Cable yarding	M	L	M	M
Horse yarding	L	L	M	L
Helicopter or balloon yarding	L	L	M	L
Clearcut harvest				
Feller-buncher yarding	H	H	M	H
Tractor yarding	H	H	M	H
Cable yarding	M	L	M	M
Horse yarding	L	L	M	L
Helicopter or balloon yarding	L	L	M	L
Biomass harvest				
Feller-buncher yarding	H	H	H	VH
Tractor yarding	H	H	H	VH
Cable yarding	M	L	H	H
Horse yarding	L	L	H	M
Helicopter or balloon yarding	L	L	H	M
Roads and landings				
Permanent - out of production	VH	VH	VH	VH
Temporary - return to production	VH	VH	VH	VH
Reconstruction	M	L	L	L

[1] "Maximum potential effects" refers to the greatest impact possible, at any single entry, should that practice be applied under the worst possible conditions without mitigation measures.
[2] L = Low potential impact, M = Moderate potential impact, H = High potential impact, VH = Very high potential impact.
[3] Tractor yarding is a term that includes both tractors and rubber-tired skidders.

Whether this worst case is reached depends upon site conditions and the skill of the operator. There are three important reasons for rating maximum potential (rather than actual or average effects) of silvicultural practices:

1. Rating practices by their maximum potential effect allows us to raise "red flags" for practices that may be particularly risky. The average or actual effect will vary by site, soil, and operator.

2. Considering the maximum potential allows comparison of practices.

3. Attention is focused on practices with high potential impact so that they will be carefully applied.

In the two sections that follow, Weatherspoon and Brown and Zinke describe how Table 1's specific ratings were developed, and further information can be found in the ***References*** section at the end of this volume.

Other Considerations

Roads and landings

In terms of forest soil productivity, roads and landings are areas that have been removed from production. Returning the soil beneath roads and landings to production usually requires ripping the soil to break up compaction that hinders seedling survival and growth (Fig. 7). Whether this is worthwhile depends on management objectives and the rotation length, whether the roads and landings are part of a permanent transportation system to be used in future harvests, and whether the remaining soil is deep enough to support tree growth.

Interactive effects

Forest management objectives often require the sequential use of several practices discussed in this chapter. Therefore, a silvicultural treatment should be seen as part of a sequence of events where the impact of one activity will affect choice of another. The timber management sequence often begins with a timber harvest. If the harvest is a clearcut, for example, it usually is followed in a year or two by a site preparation treatment, and perhaps thinning within 10 to 40 years. If harvesting is conducted carefully, and risks to productivity are minimal, then careful use of potentially high-risk site preparation practices can be considered. On the other hand, if clearcutting threatens site productivity, lower-risk site preparation practices should be used.

Choosing a system

Although some practices have high potential to affect site productivity, there may be ample reasons for using them. Unprepared or poorly prepared planting sites can fail to regenerate. Residues left untreated increase the risk and potential severity of wildfire, which may be more damaging to site productivity than residue treatment. And harvesting offers one of the few economically feasible opportunities in the forest management cycle to maintain or improve the productivity of a site through alteration of soil properties. All authors of this volume agree that the silvicultural practices discussed are useful when carefully applied under appropriate circumstances, and that rankings indicating a high potential risk for productivity loss simply are warnings to proceed with care.

Site Preparation and Residue Management

Charles J. Brown and C. Phillip Weatherspoon

During the course of preparing a site for tree regeneration or to reduce fuel loads, forest soil fertility and site productivity can be affected substantially by the way surface residues are preserved or discarded. The residues result from accumulation of plant litter on the soil surface during normal development of a forest, from slash produced in logging operations, and from operations where brushfields are cleared to plant trees (Fig. 8). Large amounts of residue can threaten fire protection measures, pest management, and stand establishment. But regardless of how residues originate, the way they are treated will strongly affect the capacity of a site to grow trees.

The techniques used to manage residues overlap considerably with those used to prepare sites for regeneration. Often, a single operation serves both purposes. In even-aged management, a site usually is prepared only once in a rotation to establish a stand, while residues may be altered at any time to modify fuel buildup or to serve other objectives. Adverse impacts are apt to be greatest during site preparation because amounts of residues are greater, heavy machinery usually is used, and the site is exposed and vulnerable to damage.

Site Preparation

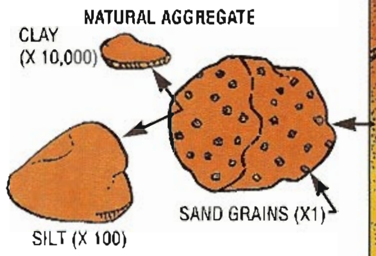
Machine piling

Piling surface residues by tractor to prepare sites for regeneration (called *"windrowing"* or *"scalping"*) can lead to substantial and lasting losses in soil fertility and site productivity (Ballard 1978; Powers, Webster, and Cochran 1988). A bulldozer, usually equivalent in size to a D-6 or larger and equipped with a blade or rake, is used to concentrate logging slash or brush into rows or piles (Fig. 3). The soil surface commonly is disturbed and, in some cases, 8 to 10 inches of topsoil are deliberately "scalped" away, often exposing a finer-textured subsoil. As a result, soil and organic matter loss and soil compaction can be high.

Continued on page 16

Figure 1. In horizontal and vertical variations in soil: soil particles are arranged into natural aggregates and layers. Sand grains are visible in a matrix of silt and clay, their individual grains are indistinguishable without magnification.

Soil Hoizons:
O, organic layer; *A*, topsoil; *B*, subsoil; *C*, parent material; *R*, bedrock



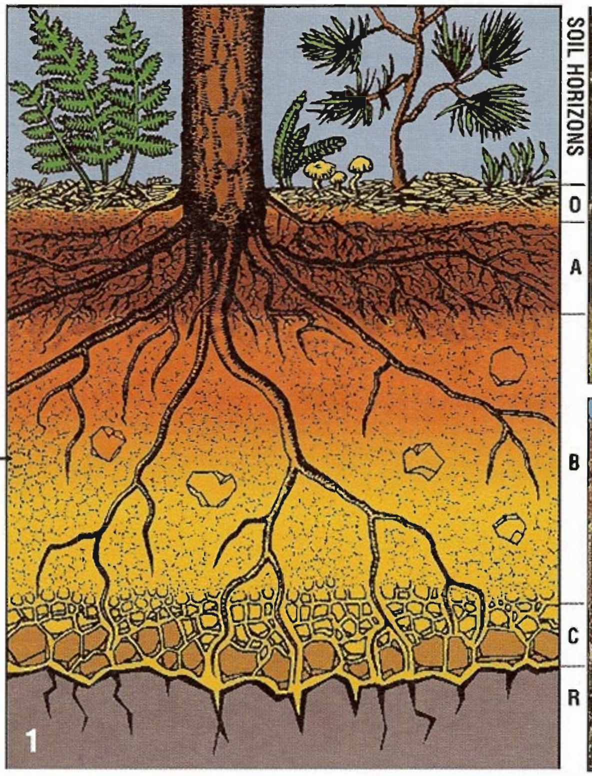


Figure 2. The legacy of old skid trails: poorer growth in the next forest. Pine trees in this plantation are growing better in less compacted soil away from the skid trail.

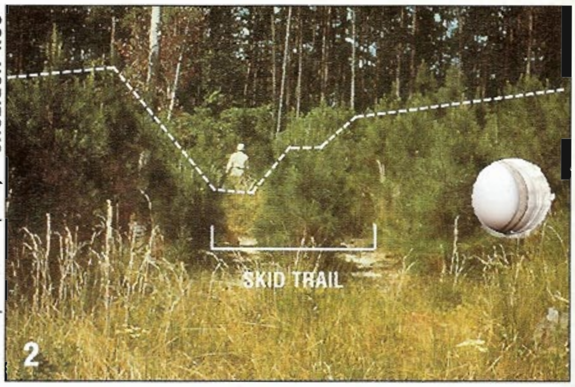


Figure 3. Surface residues and topsoil were piled by a bulldozer into "windrows" to prepare this site for planting. Soil disturbance could have been much less if a brush rake had been used, rather than a straight blade. Fertility has been lost, and the finer-textured subsoil is now exposed to erosion.

Figure 4. Seen here: the distribution of nitrogen in average forest ecosystems of Douglas-fir (DF), ponderosa pine (PP), and white fir (WF). Most nitrogen is found in the soil, with about one half contained in the top 12 inches. The forest floor has nearly the same amount of nitrogen as the standing forest.

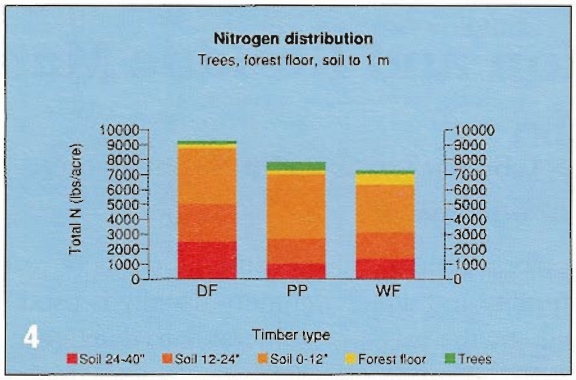


Figure 5. Soil compaction breaks down surface aggregates and reduces the volume of large pores. In turn, this restricts water and air movement, and produces very hard (sometimes waterlogged) erodible soils that impair root growth.

Figure 6. Mechanical harvesting of entire trees by shearing, an intensified utilization, removes about twice the amount of nutrients from a site as conventional, stem-only harvesting.

Figure 7. Poor aeration and increased density of the clayey soil at this compacted landing led to poor survival and growth of planted trees.

Figure 8. Logging and other operations can produce residues that pose problems to stand regeneration and fire protection.

Figure 9. Terracing was used to establish a plantation on this steep, erodible slope. The terraces follow topographic contours.

Figure 10. A contour terrace with two rows of planted trees. Using a bulldozer, soil cut from the uphill side was redistributed to the downhill side to create a level strip for planting.

Figure 11. A tractor-drawn ripper was pulled along contours in preparing this shallow soil for planting. Fracturing the underlying metamorphic rock improved planting ease and seedling survival. Erosion is minimal because of the gentle slope.

Figure 12. One-year results after a successful broadcast burning of the logging slash seen in figure 8. Erosion was minimized because some organic residues were retained.

Figure 13. One-year results after broadcast burning an area adjacent to that in figure 12. Logging slash and the forest floor were almost entirely consumed. Erosion rills are beginning to form.

Figure 14. A broadcast burn reduced fuel loads while leaving a thin layer of protection for the forest floor. The forest floor was at the top of the stake before burning.

Figure 15. Lighting a strip-head fire during underburning operations in a young conifer forest. Such low-intensity burning reduces the fuel load without degrading the soil.

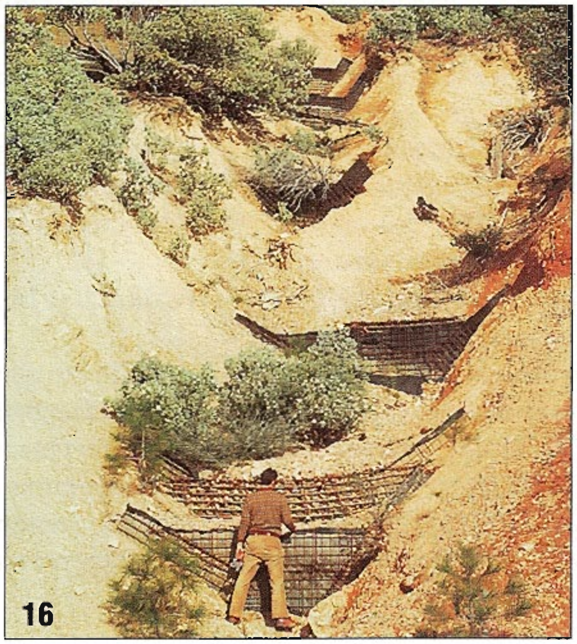


Figure 16. Severe gully erosion in a hillside above Shasta Lake. The area once supported a mixed-conifer forest before it was laid bare by sulfur fumes from smelting operations in the early 1900s. Metal "riprap" was installed during the 70-year recovery period to check erosion.

Adverse impacts of windrowing and piling can be alleviated by restricting the practice to less sensitive sites—areas with deeper soils and thicker A horizons, and with slope angles less than 35 percent. Making changes in equipment also helps. For example, substituting an open-backed brush rake for a dozer blade reduces topsoil displacement and organic matter loss. Making only one pass with the bulldozer and restricting activity to periods of low soil moisture will limit both soil movement and compaction (Sidle 1980).

An increasingly popular practice is to make openings one blade wide on the contour with bordering windrows. This adequately prepares sites after only one pass—without losing planting space to large windrows that cannot be planted even after they are burned. Often, a V-blade is used, although an angled brush blade can be used. Regardless of the procedure, it is most important that equipment operators have the skill and understanding needed to avoid adverse impacts.

An alternative for converting brushfields to productive plantations is to use herbicides to kill the brush, and then crush the brush with a bulldozer to open the area to planting. Fire also is effective in clearing certain sites for planting, provided that it does not stimulate sprouting or germination of dormant weed seeds to a degree requiring further treatment. Chipping or chopping machinery (Harrison 1975) may be practical alternatives where slopes are gentle and woody vegetation is nonsprouting.

Terracing

Terracing can adversely affect soil productivity. Terraces are a series of parallel benches generally cut one blade wide with a crawler tractor on the contour of steep slopes (Fig. 9). The aim is to create planting spots and provide planting access (Fig. 10). The effect of terracing on soil properties (and possibly productivity) is similar to, and almost always more extreme than, machine piling. And because slopes tend to be considerably steeper, potential risks are greater, too. Construction of terraces massively displaces soil from cuts to fills. Without careful allowance for proper drainage, fill slope instability and erosion can occur. Although the area between terraces acts as a filter for erosion control, it comprises 50 percent or more of the potentially productive land surface. Because of these inherent problems, alternatives involving burning, herbicides, and mechanical crushing have been developed to eliminate slash or brush and to create plantable spots on steep slopes.

Ripping/disking

Ripping, disking, chopping, or plowing are employed mainly to alleviate compaction or to reduce competition by grass and brush. Usually, these methods involve rock rippers, winged subsoilers, a disk harrow, or a range plow pulled behind a tractor, and they may be combined with other site preparation methods. Carefully following the contour of the slope will minimize potential soil loss from erosion (Fig. 11). Increasing soil porosity through disking or ripping seems to have no adverse effect on site productivity. Whether they promote tree survival or growth substantially depends on soil type, logging history, and the degree of compaction. These practices should be used to loosen soil only where the cost can be justified by improved seedling survival and future volume growth.

Herbicides

Successful establishment and growth of conifer plantations in a summer-dry state like California depends on controlling competing weeds. Herbicides are particularly effective. Of all the site preparation methods, herbicides have the lowest impact on soil properties and site productivity. Soil rarely is disturbed except by ground application. Even there, impact is minimal. Combined with other controls, herbicide applications do not disturb the soil or create soil compaction and loss (e.g., spraying and crushing brush instead of windrowing; spraying and burning instead of terracing). Mechanical site preparation alone does not always provide this control, and its effect is often outgrown in one or two years.

Broadcast burning

Using fire to eliminate slash or brush that has not been pushed mechanically into piles or windrows is called "broadcast burning" (Fig. 12). The effects of broadcast burning on site productivity vary, but the impact can be high (Boyer and Dell 1980). In some cases, productivity may even be enhanced by nutrients released from the ash. Unlike mechanical site preparation, broadcast burning is not limited by slope or topography.

Although burning does not involve mechanical site disturbance, it does have its own set of potential risks. The greatest risks can occur when soil nutrients volatilize and are lost, and when mineral soils are exposed and eroded. By consuming most or all of the protective forest floor, a highly consumptive burn can leave a site susceptible to erosion (Fig. 13). Surface erosion often is most serious where soils are derived from coarse-textured materials, such as granodiorite or pumice (Rothacher and Lopushinsky 1974). Peak temperatures generated during "hot burns" can encrust the soil's surface and create compactionlike changes as a result of the soil's heating and organic matter loss. Heated soil can also cause water repellency in the upper few inches of mineral soil, further increasing the potential for erosion. Risks can be reduced if some protective forest floor is retained by controlling the level of fuel consumption (Fig. 14). A low consumption fire (also called a "cool burn") minimizes soil exposure and can produce "dead slash" shading from larger material. This reduces soil erosion, loss of nutrients, and stress on planted trees by retaining some shade and shelter (Fig. 12). Low levels of consumption can be achieved by burning when duff and larger fuels have moderate to high moisture contents. On sites with thin O and A horizons and/or poor site quality, burning may carry severe productivity impacts and is not advisable.

Residue Management

With respect to soil productivity, residue management practices can be categorized according to whether residues are burned, rearranged, or removed from the site. More detailed accounts of the impacts of specific practices can be found in Rothacher and Lopushinsky (1974).

Understory burning

In a sense, burning is a hybrid between rearranging and removing residues. Although not removed in a mechanical sense, organic matter and some nutrients are converted to gases during burning and are lost from the site. Other nutrients, "rearranged" as ash, take a form more available for plant use. In contrast to broadcast burning in logging slash or brushfields, understory burning is applied in an existing stand of trees (Fig. 15). To protect residual trees, fire intensity (indicated by flame length) typically is less in understory burning. However, effects on soil productivity may approach those of broadcast burning in "hot spots," where fuel loads and consumption are high, but rarely are they great over most of the area. As with broadcast burning, low levels of consumption can be achieved by burning when larger fuels and duff have moderate to high moisture contents.

Rearranging residues

The common factor among these residue treatment practices is that they remove no organic matter from the site. Rather, to varying degrees, they reduce the overall depth of residues, placing them nearer the ground where they can decompose more rapidly. As decomposition increases, organic matter and nutrients are added quickly to the soil. The associated benefits are presented in chapter II.

Lop and scatter. Of all the residue management treatments, lop and scatter has the least impact on soil productivity. It involves cutting and scattering slash that extends more than a specified height above the ground, and may involve cutting long pieces into shorter lengths. This work, performed manually, assures negligible soil disturbance and compaction. Organic matter is distributed more uniformly, and slash decomposition is improved. Also, erosion potential from logging may be reduced by placing slash on skid trails and other highly disturbed areas during lop and scatter.

Chipping or chopping. Chipping has little effect on site productivity. Usually, green residues are hand fed into a small portable chipper that blows chips onto the site in a fairly uniform layer. A chip mulch is produced that, more than scattered slash, improves surface erosion protection (Benson 1982). Compaction is low because chipping equipment is lightweight. Spreading chips distributes organic matter uniformly, thereby speeding decomposition and recycling of nutrients.

Several machines have been developed to chop, crush, masticate, or otherwise reduce the size and overall depth of residues on the site (Harrison 1975). All produce results comparable to chipping. Machines that create surface mulches affect soil productivity in a way similar to those for chipping residues. Machines that mix fragments into the soil promote faster incorporation and decomposition of organic matter than do any other treatments. Avoid adverse impacts by minimizing use of equipment on soils with high clay content during moist periods, which favor compaction (Sidle 1980). Restrict chippers to skid trails and other areas already disturbed during logging. This cannot be done with choppers and other types of masticating equipment which, by necessity, must travel over most of the site.

Removing residues

Like machine-piling practices described previously, the following practices physically remove residues from the site. The organic matter and mineral nutrients contained in the residues—essential soil components of site productivity—also are taken from the site. Consequences of residue removal become more serious as more organic matter and nutrients are removed and as the size of the "bank" of organic matter and nutrients on the site decreases.

Whole-tree harvesting. The maximum potentially adverse impact of this practice on soil productivity is high (Kimmins 1977). Whole-tree harvesting simply is the removal of entire merchantable trees (normally, the aboveground material) from a harvest area (Fig. 6). Potential adverse effects of whole-tree harvesting on soil loss and compaction are high, with actual impacts depending on yarding method and operator skill. On the other hand, whole-tree harvesting leads to less soil loss and compaction than conventional harvesting coupled with cleanup of postlogging residues. Impacts and mitigating measures for soil loss and compaction generally are similar to those for conventional harvesting (see Zinke, this chapter). The potential impact of organic matter and nutrient loss from whole-tree harvesting also is high because the forest's entire nutrient-rich mass of foliage and small branches is removed. Prudence dictates that managers undertake whole-tree harvesting only on better-than-average sites and with the advice of an experienced soil scientist. Fertilizer can replace lost mineral nutrients, but not lost organic matter.

Yarding large residues. The impact on soil productivity of yarding large residues—those with diameters greater than 6 inches—is moderately adverse (Harvey, Larsen, and Jurgensen 1981). Often referred to as "YUMing" (Yarding Unmerchantable Material), it usually is practiced on public lands soon after merchantable logs have been yarded (normally with the same yarding system). Impacts of YUM on soil loss and compaction are moderate. Erosion, however, is increased not only by additional disturbance from yarding the residues, but also by the loss of residues that serve as barriers to water and soil movement (Fig. 13).

Impacts of YUM on organic matter loss also are moderate. Although large residues are low in nutrient content and slow to decay, they contain substantial amounts of organic matter that can be important to long-term productivity, particularly on less fertile soils. A related value concerns the important role of decaying wood in supporting a variety of microorganisms that sustain site productivity (Harvey, Larsen, and Jurgensen 1981). Adverse impacts of YUM can be reduced by:

1. Applying YUM only where large residues are unusually abundant.

2. Restricting equipment to skid trails or areas already disturbed during logging.

3. Observing precautions and mitigating measures explained elsewhere in the section that follows: ***Effects of Silvicultural Systems, Harvest-Methods, and Biomass Harvest on Site Productivity.***

Effects of Silvilcultural Systems, Harvest Methods, and Biomass Harvest on Site Productivity

PAUL J. ZINKE

Soil conditions influencing site productivity can be changed by silvicultural systems and harvest methods listed in Table 1. This table is meant to show the potential of each practice for decreasing site productivity, but it also is important to recognize that no practice is inherently "good" or "bad." Rather, the adverse nature of any practice depends on local site conditions and on the manner in which the practice is applied. Soil disturbance is an inescapable part of forest management, and the trick is to recognize the conditions where silvicultural systems and harvest methods must be chosen or applied with particular care.

Is All Soil Disturbance Bad?

Applied properly, some management practices offer inexpensive ways of sustaining or improving site productivity through soil disturbance. For example, yarding logs over a soil surface is like random plowing which creates a better seedbed for natural regeneration. Deep ripping of leached soils in New Zealand has improved growth of adjacent regeneration (Williamson 1985), and ripping of well-developed soils in a relatively low rainfall area in California's Klamath Mountains has increased tree survival and subsequent growth. Although there are positive aspects of soil disturbance on productivity, the potential for adverse impacts certainly is greater.

Impacts on Soil Properties

Not all adverse soil changes are due to management. Natural changes affecting productivity can and do occur in both chemical and physical soil properties. Assman (1970) found that site quality began to decline under natural conditions with increasing soil humus thickness, acidity, and clay content. Documented evidence of the long-term impacts of management practices on soil properties and site productivity is scarce. This does not mean that adverse impacts do not occur. It only means that the subject has not been studied extensively. Powers (1989) has summarized our best examples. The effects of silvicultural systems or harvesting methods on site productivity can be described in terms of chemical and physical soil properties. Chemical properties of soils may be affected adversely by losses in organic matter content (which provides storage and availability of nutrients), or by decreased return of nutrients normally cycled back to the soil. Adverse changes in physical soil properties are those that reduce the actual rooting and storage volume of soil and its physical tilth (structure and aggregate stability), which reflects soil porosity, infiltration, and aeration capacities. Adverse changes in soil properties and processes, and the conditions that trigger them, are summarized in Table 2.

Chemical changes

Continuous removal of leaf litter, somewhat parallel to intensive biomass removal, has reduced growth as much as 50 percent in Europe (Wiedemann 1937). The greater the removal of biomass, and the poorer the site, the larger the proportion of site (soil plus vegetation) nutrient elements removed during harvest. Figure 4 shows the distribution of nitrogen in trees, forest floor, and soil for coastal Douglas-fir, mixed-conifers, and true fir. Most of a site's nitrogen is stored in the soil. The trees and forest floor contain comparable amounts. In a study of intensive residue removal after timber harvest at the University of California's Blodgett Experimental Forest, Zinke et al. (1982) found that the quantity of phosphorus contained in tree residues was equivalent to about 25 percent of the soluble phosphorus in the soil. This suggests that the removal of forest residues could lead to phosphorus deficiency. A decrease in mineralizable nitrogen was found by Powers and Weatherspoon (1984) in 20-year-old clearcuts, compared with uncut areas nearby. However, no significant change in site index was found. An immediate decrease in total nutrient storage in soils was found by Zinke (1983) in soils where old-growth redwood had been clearcut, but losses apparently are recovered by the time that young-growth stands reach sawtimber size. A smaller decrease in total nutrient storage was measured immediately after clearcutting in second-growth redwood.

Physical changes

Published reports of harvesting effects on soil physical changes and resulting site productivity reduction have centered mainly on soil compaction, changes in moisture status (either too much, where the water table is near the surface—or too little, where the water table has been lowered by gully erosion), and actual soil loss (Assman 1970; Powers 1989). Recently, Froehlich (1979); Helms, Hipkin, and Alexander (1986); and Donnelly and Shane (1986) have shown growth reductions associated with soil compaction. A decline in site productivity indicated by a decrease in site index due to gully erosion of surface soil layers was found by Kittredge (1952).

Impact intensity

Extreme adverse impacts of management operations on productivity leads to such obvious symptoms as seedling mortality, reduced height growth, poor color and density of the foliage, and persistently bare ground. For instance, operations causing the loss of the A horizon of an A/C soil would leave only stony, partially weathered C-horizon material that would tend to remain infertile and barren, as has occurred from progressive deforestation and erosion of the Karst area in Yugoslavia and in Italy east of Trieste. Nearer to home are the infertile and deeply gullied soils above Shasta Lake, where sulfur fumes from the Kennett smelter devegetated surrounding hillsides in the early 1900s and led to nearly complete loss of topsoil through erosion (Fig. 16). Adverse impacts generally are less striking, and the intensity of the impact depends upon the amount and depth of soil disturbance. For example, exposed C horizon soil would indicate maximum disturbance, B horizon exposure less, and A horizon least. A forester can identify these horizons by their color, heaviness of texture, or stoniness seen in roadcuts nearby.

Ranking the Systems

Table 3 ranks silvicultural systems in order of extent of soil disturbance and amount of biomass removed in the harvest. The ranking is based on the premise that a single tree selection system has the least impact on soil (at least in the short run), while clearcut and

Table 2. Changes in soil factors that may lead to loss of site productivity

Category	Condition	Circumstances	Impact
Physical	Soil loss	Steep slopes; high rainfall; bare soil, A/C soils[1]	Reduced storage capacity for water, nutrients
	Compaction	Heavy equipment; frequent passes; moist, plastic soil	Reduced porosity, infiltration, aeration
Chemical	Soil loss	Bare soil; steep slopes; high rainfall	Reduced nutrient reserve and availability
	Removal of vegetation portion of nutrient cycles	High rainfall; intense tree and residue removal; litter layer loss	Interrupted nutrient cycle
	Excess nitrification, leaching loss, fire, removal	Bare soil; intense fire	Reduced available nitrogen
	High soil C/N[2]	Excess slash mixed into soil	Reduced available nitrogen
	Leaching, tieup due to changing soil pH	Bare soil	Reduced available phosphorus
		Old red soils; precip <20 inches; high base parent material	Reduced available phosphorus
	Leaching	Bare soil; inflow to soil from canopy and litter stopped; residue burning	Potassium and nitrogen loss

[1] A/C soils are immature soils having only an A (mainly organic matter) horizon over a stony C horizon of weathered parent rock.
[2] Ratio of carbon to nitrogen in the soil.

complete biomass harvests have the greatest potential impact. The message is not that simple however, because a single tree system requires frequent re-entries which—if ground equipment is used in yarding—could lead to greater impacts in the long run. The amount and persistence of bare soil is assumed to be proportional to the biomass removed and passes of yarding equipment. This means that silvicultural systems can be evaluated in terms of the number of trees removed, with the greatest potential for adverse impacts keyed to those systems removing the most trees. This is a simple yardstick which should be applied with caution to individual sites. For example, effects will be more intense on steeper slopes; on southerly exposures; on shallow, infertile soils; and under conditions of extremely high or low precipitation and extreme soil characteristics (acidity, alkalinity, etc.). Removing less material from a site means less disruption in the nutrient cycle and lower impacts on soil fertility. The finer the material harvested, the greater its concentration of nutrients. The relative nutrient content of above-ground tree biomass by component is ranked as follows:

foliage > twigs > branches > bark > sapwood > heartwood

Generally, the older the portion of the tree, the lower its nutrient content. Therefore, in ranking silvicultural systems or harvest methods for nutrient drain, there is less loss in harvesting only large-dimension material and leaving fine residues in the field. Whether the potential productivity loss seen in Table 1 is realized depends on the area disturbed (Table 3) and the agent of disturbance. Table 4 indicates that where disturbance impacts are greatest, wheeled or track equipment is involved. The lowest potential impacts are with aerial suspension methods. Combining the maximum area of soil disturbance in Table 3 with the relative impact of alternative felling and yarding methods in Table 4 produces the maximum potential ratings given in Table 1.

Table 3. Silvicultural systems ranked by degree of potential soil disturbance

Silvicultural system	Description	Maximum area affected and biomass removed
Clearcut (biomass harvest)	All trees felled at one cutting	90+% of area affected, all stems and crowns removed
Clearcut (conventional harvest)	All trees felled at one cutting	90+% of area affected, all commercial logs removed
Seed tree	One cut removal of mature trees with small number seed trees left	90% of area affected, 90% of trees removed
Shelterwood	Upper canopy trees removed in stages. Remaining canopy shelters regeneration	80% of area affected, 80% of trees removed
Group selection	Groups of trees removed periodically in small (<5 acre) patches	20% of area affected, 10% of trees removed
Single tree	Trees harvested singly and periodically	10% of area affected, 5% of trees removed

Table 4. Harvesting methods ranked by relative degree of disturbance

Method	Description	Ranking[1]
Feller-bunch	Mechanical felling, bunching and log yarding	1.0
Wheel or track	Separate felling, tractor log transport by skidding	1.0
Cable	Various cable orientations for skidding logs	0.4
Horse	Horse skidding	0.4
Aerial	Aerial transport of logs to landing by helicopter or balloon	0.01

[1] Relative degree of disturbance (1.0 = complete).

Summary

Forest managers have two major keys to use in assessing probable adverse impacts of harvest and silvicultural practices on site productivity. The first key is the potential area of soil disturbance (a function of the amount and size of material harvested) (Table 3). The second key is the relative impact of the actual felling or yarding method used (Table 4). Remember that Table 1 describes the *maximum potential effect*. Whether that potential is realized depends on site conditions at the time of the operation and the skill of the operator.

IV.

Sources of Assistance

William E. Wildman and David W. Smith

A published *soil survey* characterizes soil, its capabilities and limitations, at a specific site. This chapter describes soil surveys in general, sources for obtaining soil survey reports, steps in using them, and the principal features of soil surveys produced by these four agencies: USDA Soil Conservation Service (SCS), USDA Forest Service, USDI Bureau of Land Management (BLM), and California Department of Forestry and Fire Protection. Other sources of assistance and information are included here.

What is a Soil Survey?

A soil survey is a systematic process of field investigation, description, classification, and mapping of soils within a specific area by soil scientists with input from specialists in other disciplines. A soil survey report contains maps showing the geographic distribution of different kinds of soils and text describing the soils and summarizing what is known about them. The text usually interprets soil behavior under various land uses and for the management practices used at the time of mapping.

All soil surveys have the same basic objective—to map and describe different kinds of natural soil. However, surveys are adjusted according to the complexity of soil patterns, the needs of users, and/or the precision specified by the surveying agency. Thus, the intensities of field investigations (e.g., "detailed" versus "reconnaissance") may vary from survey to survey. Soil units described on maps are not necessarily uniform. Nearly all mapping units include some types of soil besides that identified by the map unit name. The kinds of inclusions (similar versus substantially dissimilar), their frequency, and their size determine how one may use the maps.

Both detailed and reconnaissance surveys provide useful soils information. Generally, however, detailed surveys are suited for project planning, while reconnaissance surveys are suited for more generalized land-use planning. Field verification of reconnaissance surveys may be desirable where more detailed information is needed. The National Cooperative Soil Survey (NCSS) provides a system of common standards and procedures for making and correlating soil surveys in the United States and in other countries. The four previously mentioned agencies that make soil surveys in California, along with the University of California, are all cooperators in the NCSS, and the Soil Conservation Service has been designated by Congress as the NCSS lead agency. The standards used in the NCSS have been developed jointly by cooperators, have been field tested, and are revised periodically to meet changing technology. These common standards help users understand soil survey information published by different NCSS agencies.

Getting Started

Sources of information

California's most comprehensive list of soil and land classification surveys is entitled *An Index to Soil Surveys in California,* and was prepared in December 1982 (2nd edition, June 1986) by the California Department of Conservation. This publication describes and shows the areas covered by soil surveys as prepared by the following agencies:

- USDA Soil Conservation Service
- USDA Forest Service
- USDI Bureau of Land Management

- California Department of Forestry and Fire Protection
- University of California

The Index also describes and shows areas covered by land classification surveys (which contain some soils information) as prepared by the USDA Bureau of Reclamation (BOR) and the California Department of Water Resources (DWR). Descriptive sections contain information on the purpose, content, level of detail, and availability of the soil surveys from each agency. Maps are included that show the areas of the state in which soil surveys have been published, completed but not published, or are in progress. The Index lists counties alphabetically, and all soil surveys available for a county are listed chronologically. Also given are the date of publication, agency, type of survey, report status, scale, and coverage. The Index may be obtained for $5.50 at the following address:

California Department of Conservation
P.O. Box 2980
Sacramento, CA 95812
Phone: (916) 445-5716

Checks and money orders should be made payable to the Division of Mines and Geology. The Index also is available for over-the-counter purchase in Sacramento, Pleasant Hill, and Los Angeles. Call the phone number listed above for exact locations. Besides the agency sources of soil surveys listed in the Index, soil surveys also may be found at:

- Public Libraries
- UC Cooperative Extension county offices (sometimes listed as "County Farm and Home Advisors' Office")

Using a Soil Survey

General steps:

1. Obtain a soil survey that covers the area of interest.
2. Consult the index map to determine the number of the map sheet covering that area.
3. Locate the area of interest on the map sheet by legal description or known proximity to towns, roads, streams, etc.
4. Note the symbols for the soil map units included within the area.
5. Identify the name of the soil map unit for each symbol.
6. Consult the table of contents or index to map units to find and read the descriptions of soil map units and series.
8. Consult interpretive sections to find the capabilities and limitations of each map unit for agriculture, range, forestry, or other uses.

Types of Soil Surveys and Their Availability

USDA Soil Conservation Service Soil Surveys

Overview. From 1900 to 1958, soil surveys were published on colored planemetric maps, first by the U.S. Department of Agriculture Bureau of Soils, then by the Bureau of Plant Industry, and finally by the Soil Conservation Service. Most of the planemetric maps have been replaced by recent surveys on an aerial photo base, the first in California being published in 1961. Much of the privately owned land in California is covered now by the more recent SCS soil surveys. Both detailed surveys (farmlands, urbanlands, and some wildlands) and semi-detailed surveys (some wildlands) are available. Generally, a survey covers only part of a county, so the Index to Soil Surveys should be consulted to ensure proper coverage. For more information contact:

State Soil Scientist
Soil Conservation Service
2121-C 2nd Street
Davis, CA 95616
(916) 449-2872

Index to map sheets. The more recent aerial photo soil maps are either bound into the survey reports or are enclosed as individual sheets corresponding to 7.5 minute U.S. Geological Survey (USGS) quadrangle maps, and an index to map sheets is bound in the back of the report. The index shows the map sheet outlines in relation to major highways and cities, and Townships and Ranges.

Locate site on map sheet. The legal description of the area of interest can be found using the Township and Range numbers printed along the map borders. Each Township and Range contains 36 Sections, each approximately 1 mile square. Their boundaries are shown by lines on some maps, or by "+" marks at the Section corners on others. Section numbers are located either in the center or at the corner of the Section. Land in Spanish land grants does not have a Township-Range-Section description. Sites in these areas must be located by proximity to towns, roads, streams, etc. For soil maps on an aerial photo base, the photo detail often is helpful.

Soil map unit symbols. Soil maps published before 1978 used letter symbols to identify soil map units. More recent soil surveys use numbers for map unit symbols, starting at 100 with the map units arranged alphabetically

Identifying the soil map unit. Aerial photo soil maps have a soil legend in the report on the opposite side of the Index to Map Sheets, and there is a Guide to Map Units a page or two in front of this. The most recent soil surveys contain an Index to Map Units following the Table of Contents in the front of the report

Descriptions of soil map units. The Table of Contents, the Guide to Map Units, or the Index to Map Units can be used to find map unit descriptions in the report. Earlier reports describe the map units in separate paragraphs following a general description of the soil series and usually include a typical soil profile description for the series. In recent reports, the map units are described in numerical (and alphabetical) order in one section of the report, and the description of the soil series and typical profile appear in a separate section. Many of the terms used in these sections are defined in a Glossary contained in each survey report.

Tables and interpretive sections. Tables and interpretive sections of the soil survey provide more detailed information about soil characteristics and give relative ratings of the suitability or limitations of the soil for various land uses. Most survey reports with significant amounts of forestland also contain tables indicating site indices for the major timber species.

USDA Forest Service Soil Surveys

Overview. The Forest Service has completed semi-detailed (and some reconnaissance and detailed) soil resource inventories within the boundaries of all National Forests in California. Most of these reports are available in published form. Copies are also available for in-house use from individual National Forests. Blocks of privately owned land within the boundaries of the forests usually are covered by these surveys. Consult the Index to Soil Surveys for a coverage map and listings. The Forest Service also is supplementing its reconnaissance inventories with detailed surveys for critical project planning areas of federal land on an "as needed" basis. There are no plans to publish the detailed surveys, but they are available for in-house use from each National Forest. The CDF Soil-Vegetation Survey plans to make detailed surveys on some of the blocks of privately owned land within National Forest boundaries. Soil-vegetation surveys also were prepared by the Forest Service during the 1950s and 1960s on some National Forest lands (some published, some not). Contact individual National Forests for specific information. Further information can be obtained from:

Regional Soil Scientist
U.S. Forest Service
630 Sansome Street
San Francisco, CA 94111
(415) 705-2818

Index to map sheet. A soil map sheet index is either bound into the report or enclosed as a separate sheet depending upon the format used by the individual forest.

Locate site on map sheets. The map sheets generally are on a USGS topographic base map (15 minute or 7.5 minute depending on the individual Forest, and sometimes are photo reduced). A site can be located by legal description or by use of topographic and cultural features.

Soil map unit symbols. Map symbols are numerical or alphabetical, depending on the individual forest.

Identifying the soil map unit. The format varies by the individual forest, but an index to the map units is included in each report.

Description of soil map units. Again the format varies by the individual forest (some narrative, some tabular). All reports contain soil map unit descriptions and soil series descriptions.

Tables and interpretive sections. Most of the tables and interpretive sections are similar to those in SCS soil surveys. Some of the surveys contain more and different interpretations than given in SCS reports, some contain less. Interpretations for forestland management are well covered in these reports.

USDI Bureau of Land Management

Overview. In California, the BLM administers about 16 million acres of land, mostly rangeland or desert. Its surveys, which may include intermingled and adjacent private lands, are mainly designed for general planning, and the level of detail varies. Some BLM lands are included in SCS Soil Survey reports. Surveys covering other BLM lands may be available through the agency. Consult the Index to Soil Surveys for coverage and listings. Or contact:

State Soil Scientist
Bureau of Land Management
Federal Office Building
2800 Cottage Way
Sacramento, CA 95825
(916) 484-4701

California Department of Forestry and Fire Protection Soil-Vegetation Surveys

Overview. The California Soil-Vegetation Survey was established in 1947 and has mapped more than 10 million acres of detailed soil surveys on privately owned forest and rangeland in 18 counties. A map showing areas of the state covered by soil-vegetation surveys through 1986 is included in the Index to Soil Surveys in California. Each soil-vegetation map is a 7.5-minute quadrangle on a planimetric base (without contours), usually at a scale of 1:31,680 (more recent maps at a scale of 1:24,000). A booklet of tables and a users guide accompanies each map, so only those quadrangles of interest need to be purchased. A list of available maps and information on prices may be obtained from:

Soil-Vegetation Survey
California Department of Forestry
and Fire Protection
6105 Airport Road
Redding, CA 96002-9422
(916) 225-2441

Index to map sheets. Each soil map sheet and accompanying tables stand alone, so there is no index to map sheets comparable to SCS soil surveys.

Locate site on map sheet. Major highways and water bodies are shown on the soil-vegetation map. Section lines generally are shown. (Section numbers were left off the older maps and are included on recent maps.) Consult corresponding USGS topographic maps to locate a specific area of interest.

Soil map unit symbols. Each map unit delineation contains a symbol for the soil, a symbol for the vegetation, and a site quality symbol for commercial timber areas. Symbols are explained in detail in the accompanying tables and users guide.

Identifying the soil map unit. The tables with each soil map list the soil series represented by each map symbol.

Descriptions of the soil map units. There are no text descriptions of map units comparable to those in SCS soil surveys in Soil-Vegetation Survey reports published before 1987. Instead, the general characteristics of the soil series are given in Table 1 of the booklet for each soil map, and Table 2 of the booklet lists each soil series and phase and gives selected behaviorial characteristics. Soil-Vegetation Survey reports published in 1987 and later contain soil map unit descriptions in part tabular and part narrative format.

Tables and interpretive sections. Table 2 of the quadrangle booklet lists timber and range productivity estimates, erosion hazard ratings, and hydrologic soil groups. Table 3 lists the plant species mapped and rates their sprouting nature and browse value. Other tables contain data on vegetation sampling plots, a list of plant species recorded in the quadrangle, and the taxonomic classification of the soils. Survey reports produced in 1987 and beyond contain the information above and other interpretive information in soil map unit descriptions and in interpretive tables similar to those in SCS soil surveys. Also, CDF and SCS are working together to produce detailed soil and vegetation surveys in some wildland areas of California.

Other Soil Survey Features

Some soil surveys also contain general sections that provide an overview of the survey area and its soils.

General nature of the area. This section is found in most SCS and BLM soil surveys. It contains some or all of the following subheadings: History and Agricultural Development, Population Trends, Physiography, Relief and Drainage, Geology, Natural Vegetation, Climate, Water Supply, Transportation, Farming, and Community Facilities.

General soil map. This is a small-scale colored map on a single sheet, usually bound in SCS and BLM soil surveys reports. The mapping units are associations of soil series that occur near each other on similar landscape positions and are described in the text. The general soil map provides a broad picture of the soil and topographic relationships over the entire area. Such a map is useful for areawide planning and management, but is not appropriate for determining soil conditions on a specific site.

Soil formation and classification. These sections are found in SCS and BLM soil surveys, and a table of taxonomic classification is included in CDF Soil-Vegetation surveys. This information is particularly valuable to soil scientists and geologists.

Other Sources of Assistance

Addresses and phone numbers of agency soil survey program leaders have been given in the sections of this chapter that describe each agency's program. Other sources of assistance for using and understanding soil survey reports, for obtaining additional or more detailed soils information, and for possible field investigation are listed below.

Local Soil Conservation Service offices. Soil conservationists are found in nearly all counties; field soil scientists are located in areas of on-going soil surveys, and area soil scientists are stationed in six area offices in California.

U.S. Forest Service District or Forest Supervisor offices on individual National Forests. Soil scientists are available at almost all forests.

UC Cooperative Extension county offices (sometimes listed as Farm and Home Advisors office). Resource specialists with soils expertise (and some soil scientists) are usually available.

California Department of Forestry and Fire Protection Regional Headquarters and Ranger Unit offices. Local service foresters sometimes have soils expertise or can locate appropriate specialists.

Other federal agencies (BLM, BOR, USDI Bureau of Indian Affairs) and state agencies (DWR, Department of Conservation). These may have soil scientists or resource specialists available with soils expertise.

Research agencies (USFS Pacific Southwest Forest and Range Experiment Station, USDA Agricultural Research Service) and universities.

Private consultants in soil science and private firms offering soil science services. A listing of individuals and firms offering such services can be obtained from:

The Professional Soil Scientists Association
of California
c/o Department of Land, Air and Water Resources
139 Hoagland Hall
University of California
Davis, CA 95616

Afterword

Is sound soil management important to sustained site productivity? The sum of these chapters is a resounding "Yes!" Important to the continued health and growth of our forests and to the generations that follow. Can you, a forestland manager, make a difference? Yes, you can, by the choices you make. And the aim of this volume is to help you make choices that sustain your land's productivity.

Every forest manager, regardless of acreage or management objectives, must make choices: in the silvicultural system, in the method of harvest, and in the methods of preparing the site for regeneration. Each decision you make leads to other choices. Should you log an area by tractor? Or by a cable-yarding system? What time of year will you log? Should you prepare a site by tractor, piling the logging slash? Or by broadcast burning? What about yarding the material off the site? Taken individually, any one choice may have only a modest impact. But have you considered the cumulative effect, once your choices are imposed in a sequence on the land?

Certain practices (road and landing constructions, for example) obviously take portions of the land from production, but are considered a normal cost of operation. The fact that poorly constructed or ill-placed roads can lead to serious erosion or even catastrophic slope failure is obvious, and has not been discussed here in any detail. The less-obvious effects—compaction and the loss of nutrient-rich surface materials—are discussed at greater length, and each chapter provides references for further details. These references also describe management activities not covered, or touched only lightly in this volume. Many are too specialized to be found at public libraries, but they can be obtained through the University of California Cooperative Extension agent serving your area.

This volume will be most helpful when forest managers think of potential impacts as more than isolated events, because good soil management is the sum of all past practices. The authors hope that the information presented here will raise your awareness and interest in the health of forest soils, and that your management plans will incorporate concerns for this resource.

As stated in the Foreword, an underlying subject of this publication is dollars. Most economic analyses of forest management options fail to consider that a single management practice can reduce site productivity because of its impact on the soil. As Routledge (1987) points out, productivity in future rotations can drop suddenly following the first harvest, or it can decline slowly in successive rotations. Conventional economic analyses that ignore potential productivity losses are unrealistic. A guide to more realistic economic analysis has been prepared by the U.S. Forest Service (Watershed and Air Management Staff 1987).

Dollars aside, there is little pride in a management that passes the land in poor condition to the next generation. History tells us that the penalty for poor soil management is lowered productivity—first for the land, then for society. Thus, the conclusion is obvious: soil productivity is the key to forest growth and to our future prosperity.

—John L. Ronald

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